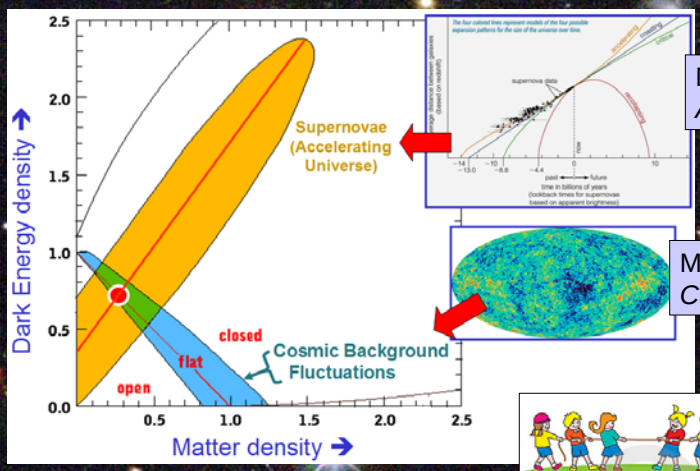
What is the Universe Made Of ?



Measures *Acceleration*

Measures *Curvature*

Acceleration = (Dark Energy) – (Matter)

Curvature = (Dark Energy) + (Matter)

What is the Universe Made Of ?

This is the only part we see.

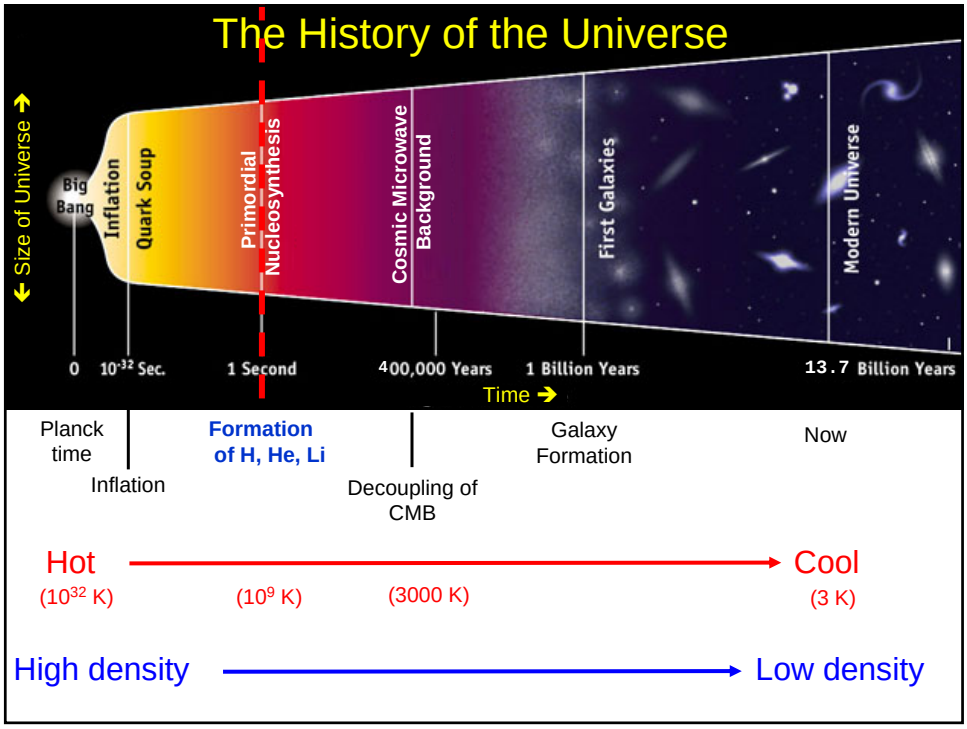
4% ~~15%~~ Normal Matter

- protons, neutrons, electrons.
- arranged into *atoms*

23% ~~85%~~ Dark Matter

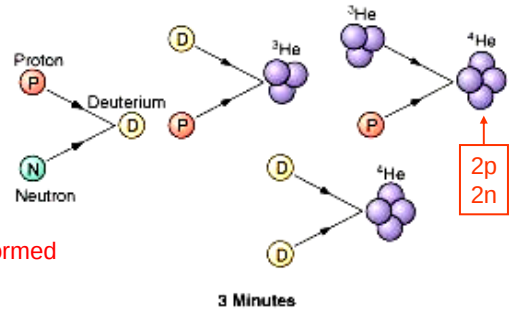
We infer it is there, but we don't know what it is.

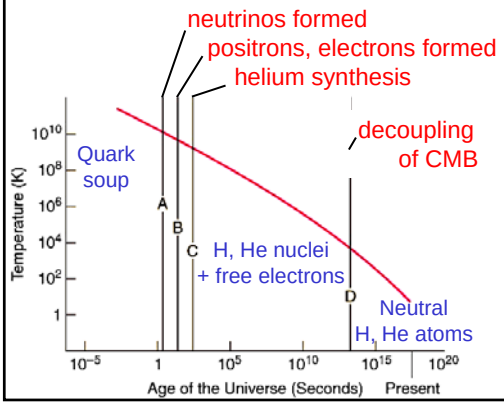
73% Dark Energy (using $E = mc^2$)



Where did Hydrogen and Helium come from?

- Nucleosynthesis in the Big Bang.
- First 3 minutes.

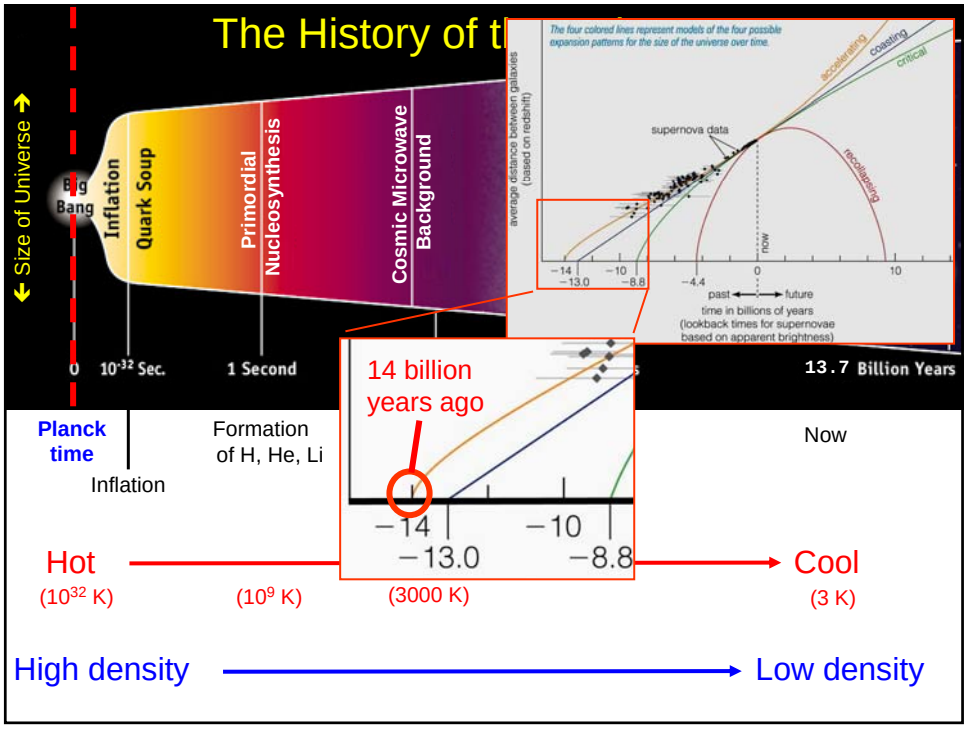


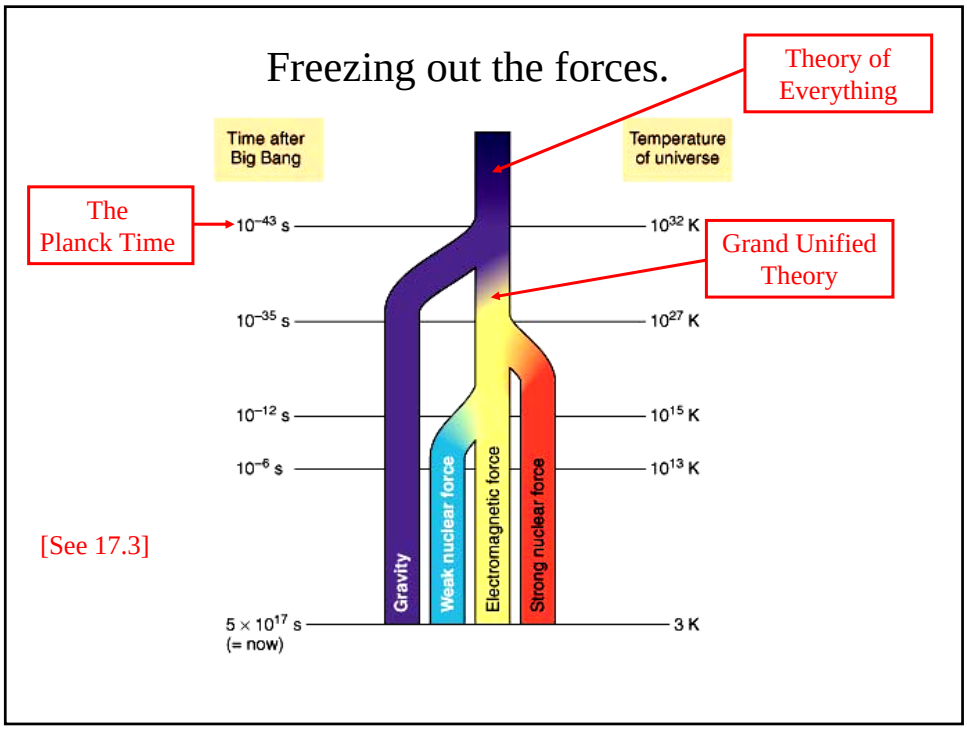


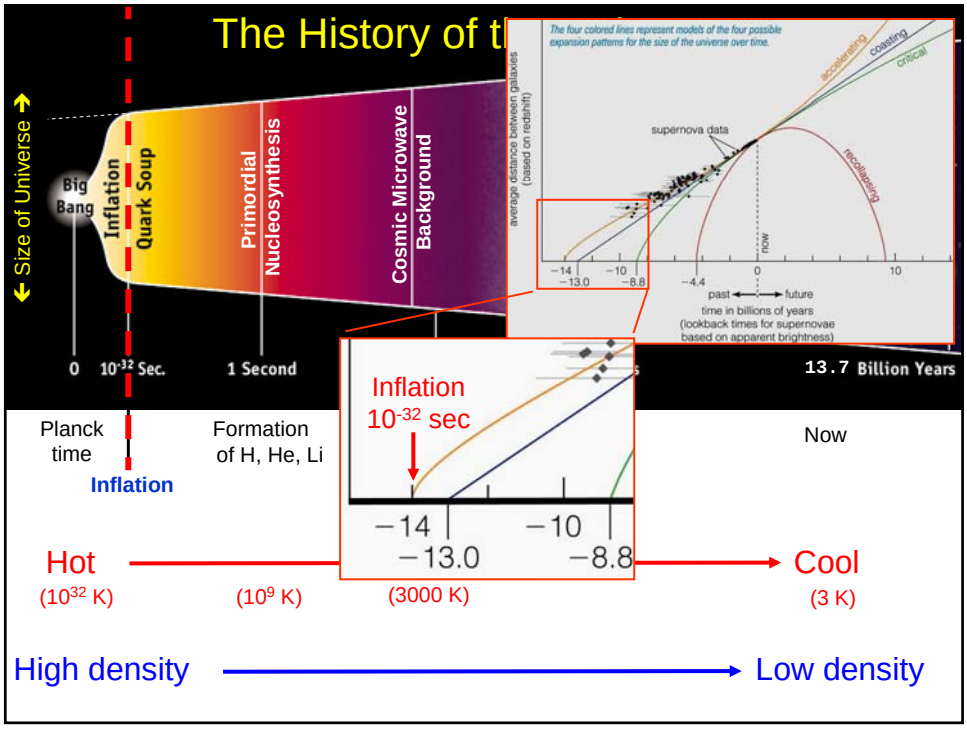
Produced 75% H
25% He

Some Lithium also formed

Then all heavier elements formed by *stars*.


The History of t
Size of Universe
Big Bang
Inflation
Quark Soup
Primordial Nucleosynthesis
Cosmic Microwave Background
0
10⁻³² Sec.
1 Second
13.7 Billion Years
The four colored lines represent models of the four possible expansion patterns for the size of the universe over time.
accelerating
coasting
critical
recollapsing
supernova data
average distance between galaxies (based on redshift)
now
past
future
time in billions of years
(lookback times for supernovae based on apparent brightness)
14 billion years ago
−14
−13.0
−10
−8.8
Planck time
Inflation
Formation of H, He, Li
Now
Hot
(10³² K)
(10⁹ K)
(3000 K)
Cool
(3 K)
High density
Low density


Freezing out the forces.
Theory of Everything
Time after Big Bang
Temperature of universe
The Planck Time
10⁻⁴³ s
10³² K
Grand Unified Theory
10⁻³⁵ s
10²⁷ K
10⁻¹² s
10¹⁵ K
10⁻⁶ s
10¹³ K
[See 17.3]
Gravity
Weak nuclear force
Electromagnetic force
Strong nuclear force
5 × 10¹⁷ s
(= now)
3 K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Formation of H, He, Li
Now
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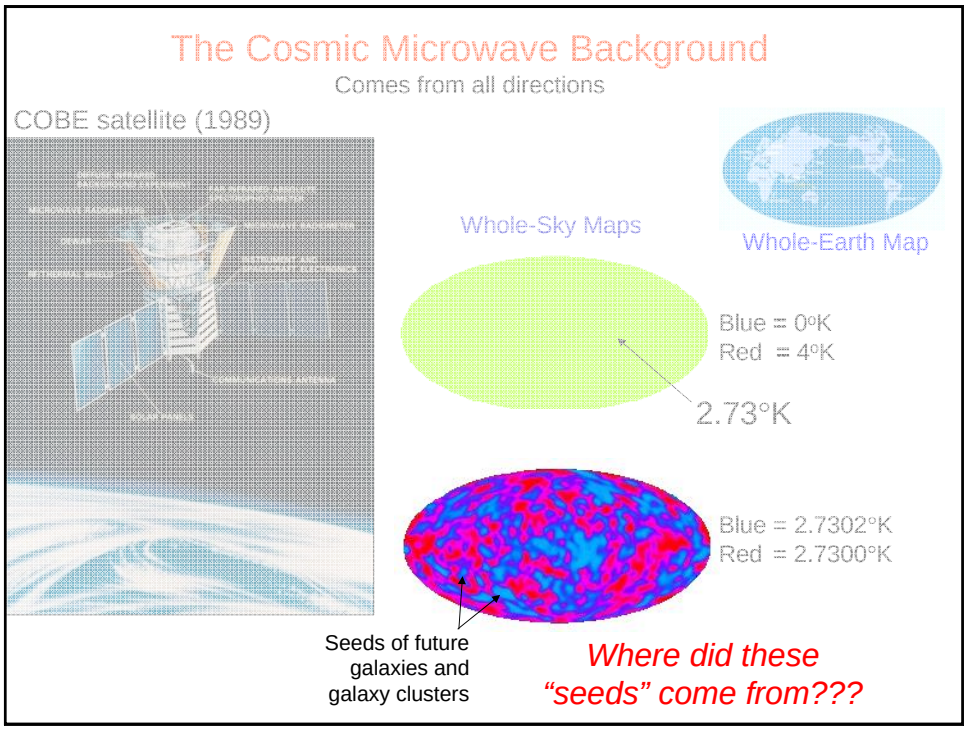
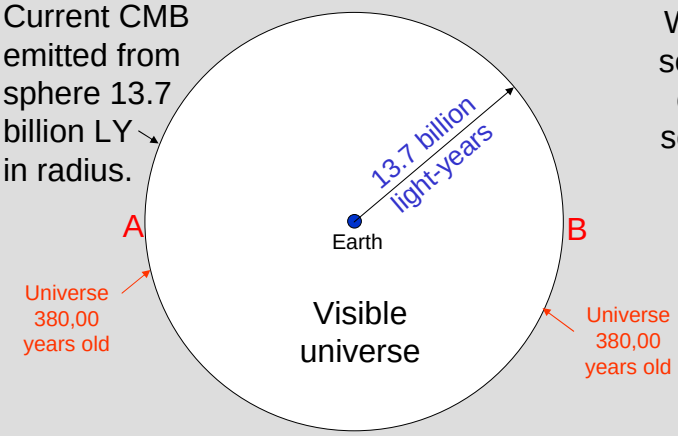
(10^32 K)
(10^9 K)
(3000 K)
Cool
(3 K)
High density
Low density


The Cosmic Microwave Background
Comes from all directions
COBE satellite (1989)
Whole-Sky Maps
Whole-Earth Map
Blue = 0°K
Red = 4°K
2.73°K
Blue = 2.7302°K
Red = 2.7300°K
Seeds of future galaxies and galaxy clusters
Where did these "seeds" come from???

The Horizon

Current CMB emitted from sphere 13.7 billion LY in radius.

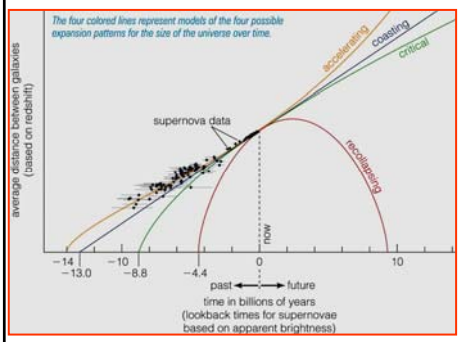
We will only see this part of universe sometime in future.

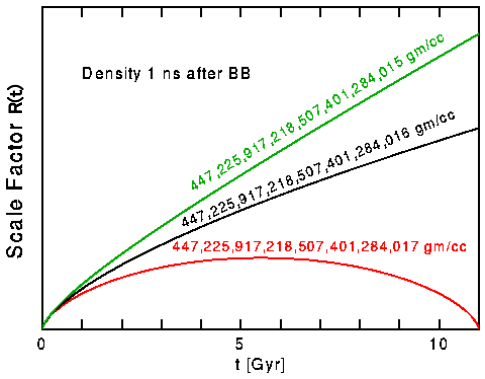


The Horizon Problem: Causality

- Points A and B have *never* communicated.
- How do they know how to have almost *exactly* the same conditions?

What happened back at the Big Bang?





The Flatness Problem:

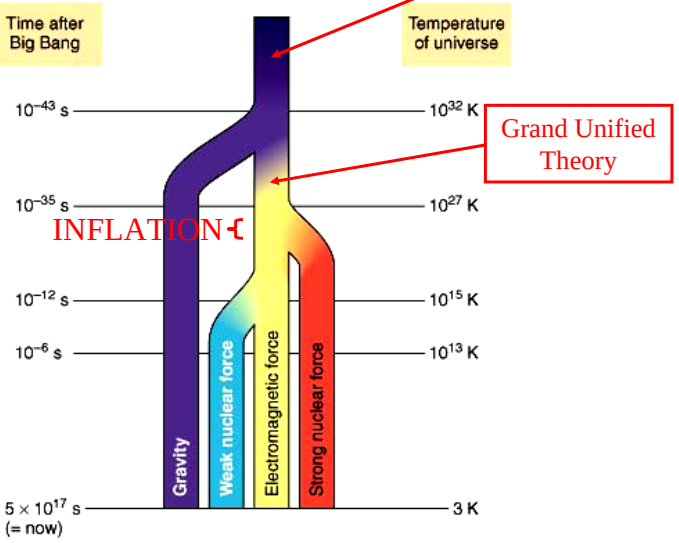
- Early universe: Dark Energy not important.
- Flatness required gravitational, kinetic energy in exact balance.

Critical Density

- But this requires incredible precision at start (t = 0).

Freezing out the forces.

Theory of Everything



[See Fig 17.3]